MICHAEL E. KISER

Michael E. Kiser is a registered Professional Engineer with over twelve years of experience in electric system planning and system design. Mr. Kiser is the president and owner of MK Power Solutions, Inc., an engineering design and consulting firm based in Ohio. Mr. Kiser is experienced in all aspects of electric system improvement and construction, including specifying major equipment, design management, coordination of construction contracts and project commissioning. Mr. Kiser performs transmission and distribution improvement, protective relay and fuse coordination, load flow and short circuit studies for the design, planning and analysis of electrical power systems. Mr. Kiser assists clients with developing and implementing electric system improvements such as power substation construction, transmission line construction, distribution feeder improvements, power factor correction, new services and new transmission delivery points.

While with a previous employer, Mr. Kiser performed regional transmission load flow analyses to address technical issues associated with utility mergers. Results of these studies were submitted in testimony to the Federal Energy Regulatory Commission (FERC) and other regulatory commissions. Mr. Kiser has also assisted industrial energy users and state consumer advocacy groups to assess technical matters such as planned transmission projects, transmission system constraints and impacts of selling generating assets. Mr. Kiser also assisted several large industrial clients in Ohio and in neighboring states with the evaluation of power supply arrangements.

Mr. Kiser served as a project design engineer for a manufacturer of large diesel and natural gas engines. He provided quotations, design and project management support for diesel/natural gas engine package systems. The applications of these engines included power generation, oil well servicing, comfort cooling and petroleum pump stations. He was the project manager for the development of innovative control systems for Schlumberger-Dowell, the largest oil well service company in the United States. He also served as the electrical project engineer for a joint venture research and development project with a major HVAC company for the application of natural gas engine/chiller packages for comfort cooling.

Mr. Kiser also was employed by a refined petroleum products transportation pipeline, as a project engineer. He planned and designed power distribution systems for new pipeline facilities and improvements to existing facilities. He was responsible for the design, specification and implementation of substation equipment, switchgear, induction motors and related equipment. He was also a member of the sequence/control group responsible for developing and implementing control system strategies for the control and protection of pipeline systems.

Education

The University of Toledo
B.S., Electrical Engineering (specializing in Power Engineering), 1992

Registration

Professional Engineer — Ohio

Professional Organizations

The Institute of Electrical and Electronics Engineers, Inc.

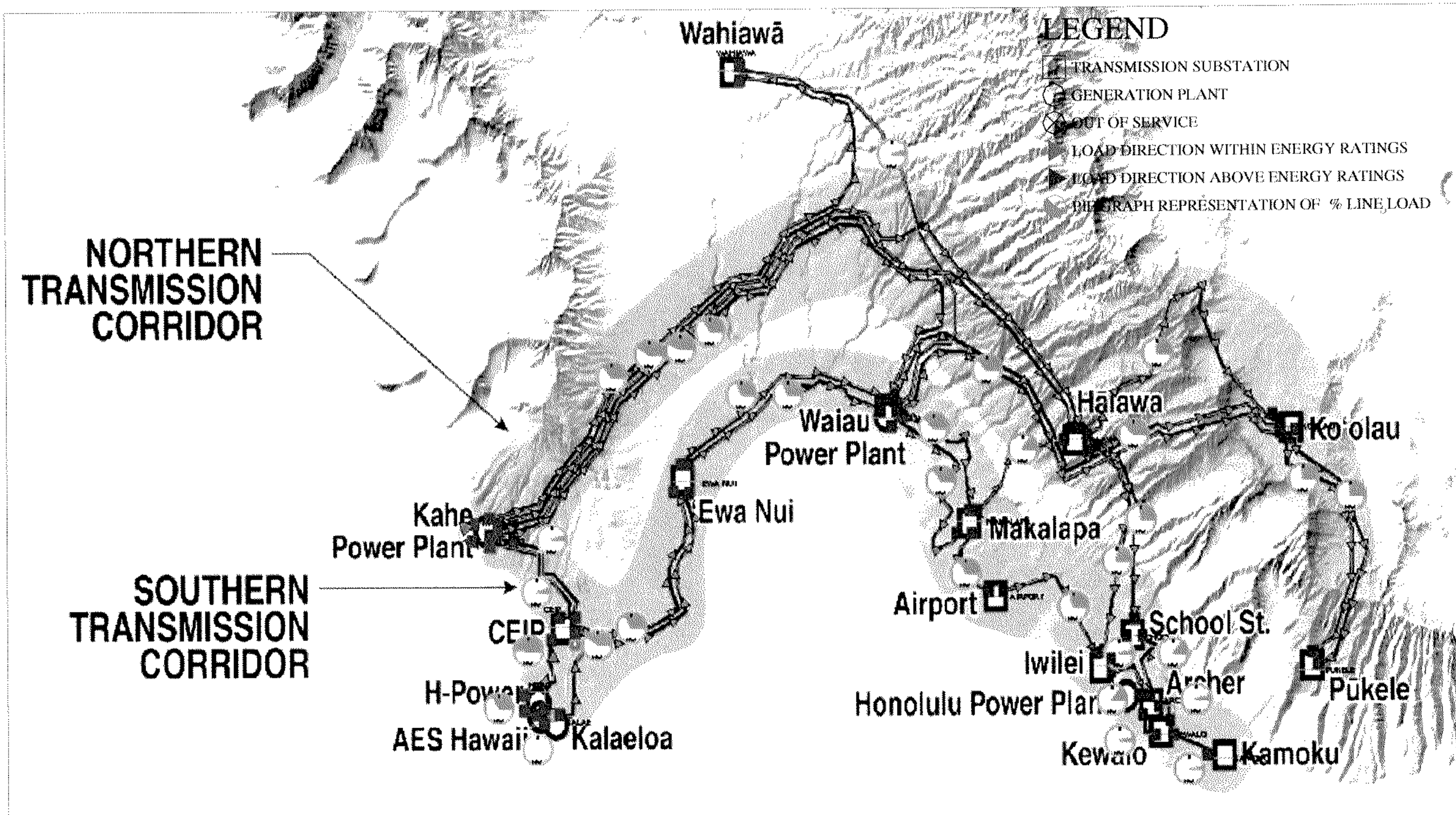
PROJECTS INVOLVING REGULATORY FILINGS

Michael E. Kiser, P.E.

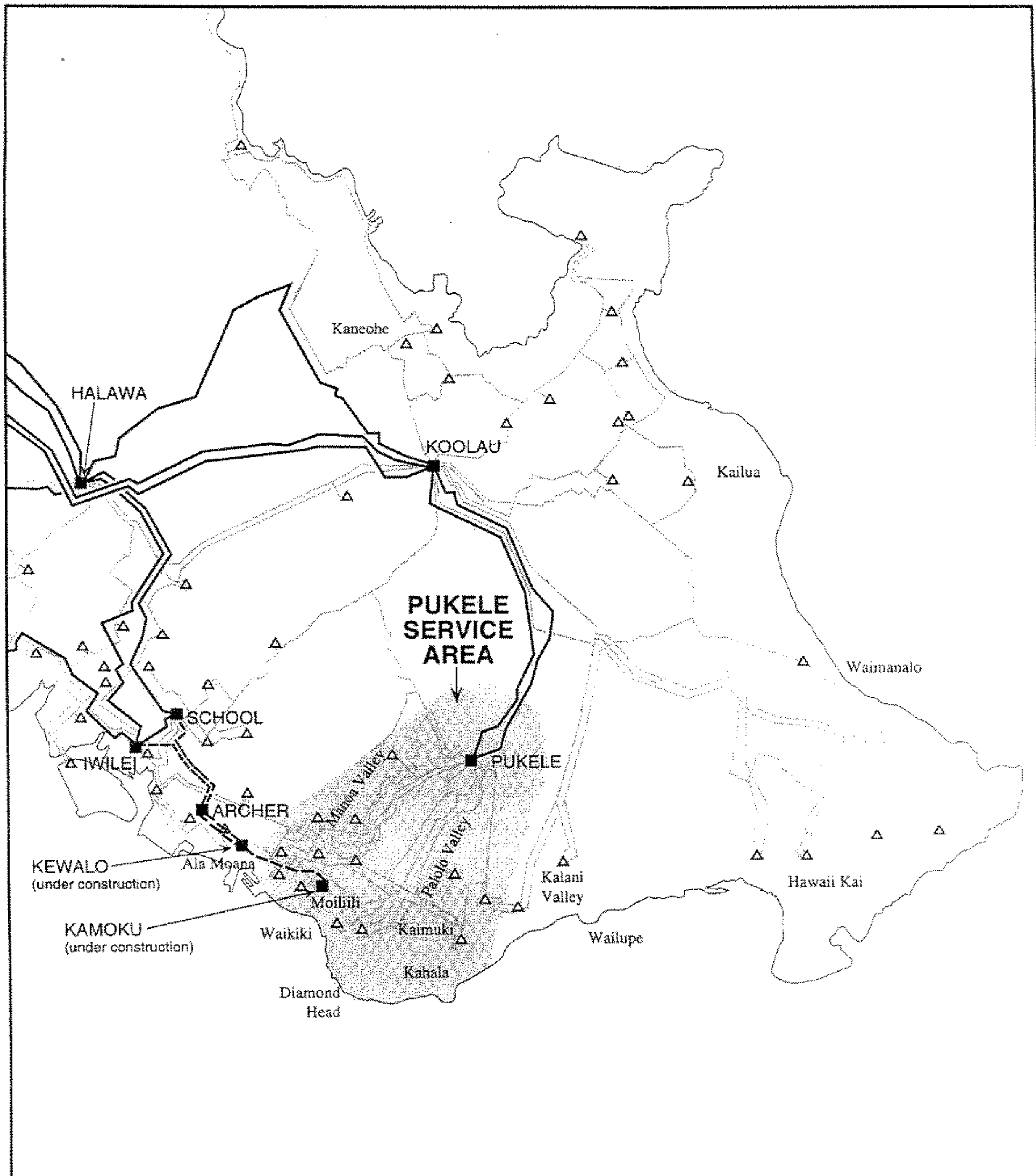
Utility	Proceeding	Issues and/or Scope	Client	Year
Federal Energy Regulatory Commission:				
Western Resources and Kansas City Power & Light	Docket No. EC97-56-000	Western Resources Merger Intervention and other related relief	Kansas City, Kansas Board of Public Utilities	1999
Western Resources and Kansas City Power & Light	Docket No. ER97-4669-000	Western Resources Merger Intervention and other related relief	Kansas City, Kansas Board of Public Utilities	1999
FirstEnergy Operating Companies	Docket No. EC97-5-000	IEU/FirstEnergy Merger Intervention and other related relief	Industrial Energy Users of Ohio	1997
FirstEnergy Operating Companies	Docket No. EC97-413-000	IEU/FirstEnergy Merger Intervention and other related relief	Industrial Energy Users of Ohio	1997
Hawaii Public Utilities Commission:				
Hawaii Electric Light Company, Inc.	Docket No. 99-0355	Need for transmission system improvements	Division of Consumer Advocacy, State of Hawaii	2000
Hawaii Electric Light Company, Inc.	Docket No. 99-0207	Review of HELCO 1999 Rate Case	Division of Consumer Advocacy, State of Hawaii	2000
Hawaii Electric Light Company, Inc.	Docket No. 99-0346	Need for capacity additions/review of IPP Purchase Power Agreement	Division of Consumer Advocacy, State of Hawaii	1999
Hawaii Electric Light Company, Inc.	Docket No. 98-0013	Need for capacity resource additions	Division of Consumer Advocacy, State of Hawaii	1999
Hawaii Electric Light Company, Inc	Docket No. 97-0420	Review of HELCO 1997 Rate Case	Division of Consumer Advocacy, State of Hawaii	1999

PROJECTS INVOLVING REGULATORY FILINGS
Michael E. Kiser, P.E.

Utility	Proceeding	Issues and/or Scope	Client	Year
Hawaii Electric Light Company, Inc	Docket No. 97-0349	Review of HELCO Integrated Resource Plan	Division of Consumer Advocacy, State of Hawaii	1999
Kansas Corporation Commission:				
Western Resources and Kansas City Power & Light	Docket No. 97-WSRE-676-MER	Western Resources Merger Intervention and other related relief	Kansas City, Kansas Board of Public Utilities	1999
Ohio Public Utilities Commission:				
FirstEnergy Operating Companies	Case No. 98-1636-EL-UNC	Transmission system reliability - sale and transfer of generating assets	Industrial Energy Users of Ohio	1999



HECO Existing 138kV Transmission System



Legend

- ■ 138-kV Substation
- △ 46-kV Substation
- ——— 138-kV Overhead Transmission Line
- — — 138-kV Underground Transmission Line
- ······· 46-kV Overhead Subtransmission Line
- · · · · 46-kV Underground Subtransmission Line

Revised Final Environmental Impact Statement
Kamoku - Pukele 138-kV Transmission Line Project

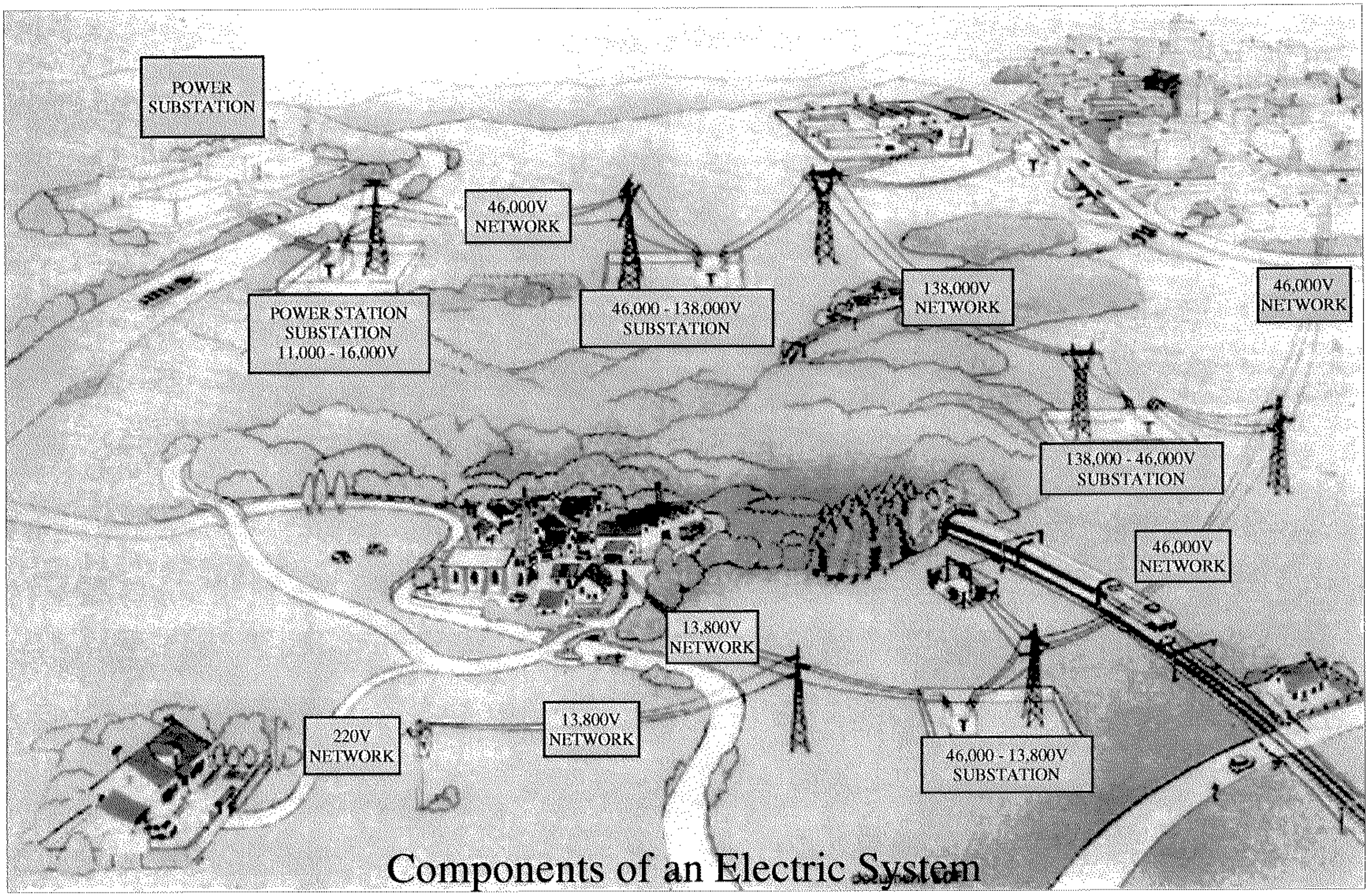
Hawaiian Electric Company, Inc.

EXISTING PUKELE SERVICE AREA

0 1 2 3 4 5
SCALE IN MILES

FIGURE
2-4

CH2M HILL



Components of an Electric System

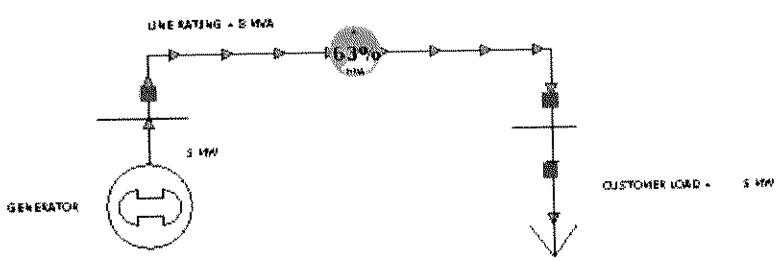


FIGURE 1

SYSTEM OPERATING NORMALLY

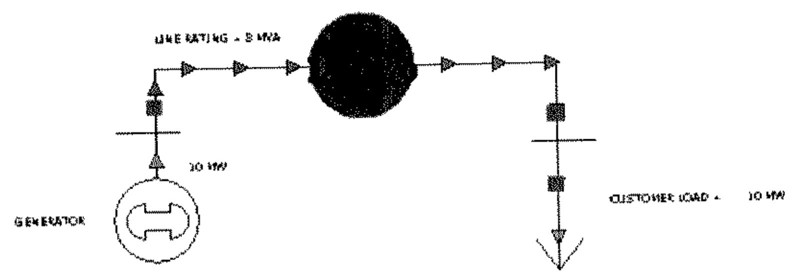


FIGURE 2

LINE IS OVERLOADED

Example of Line Overload

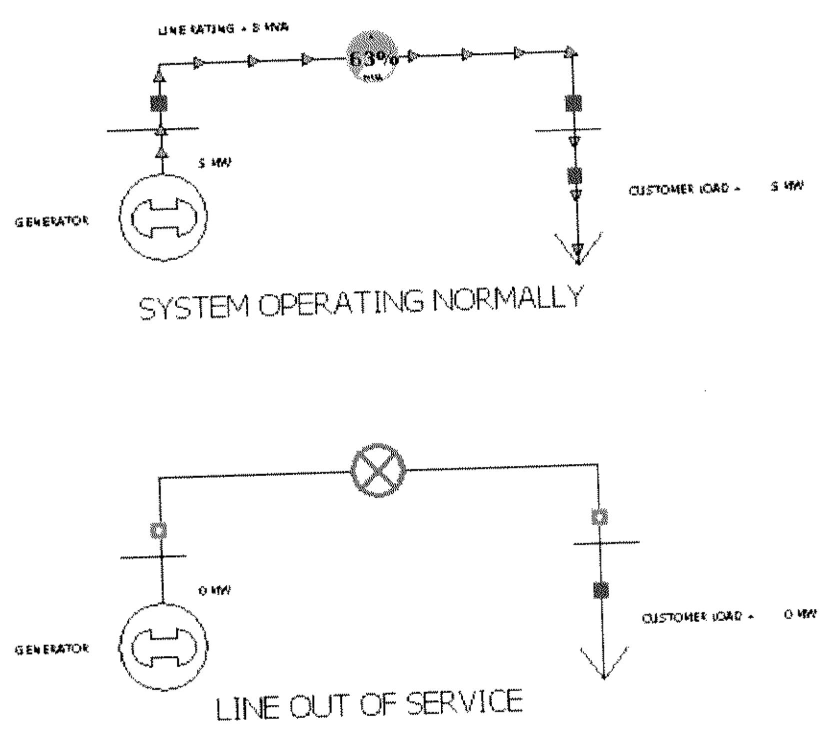


FIGURE 1 - LESS RELIABLE

LOSS OF CUSTOMER LOAD

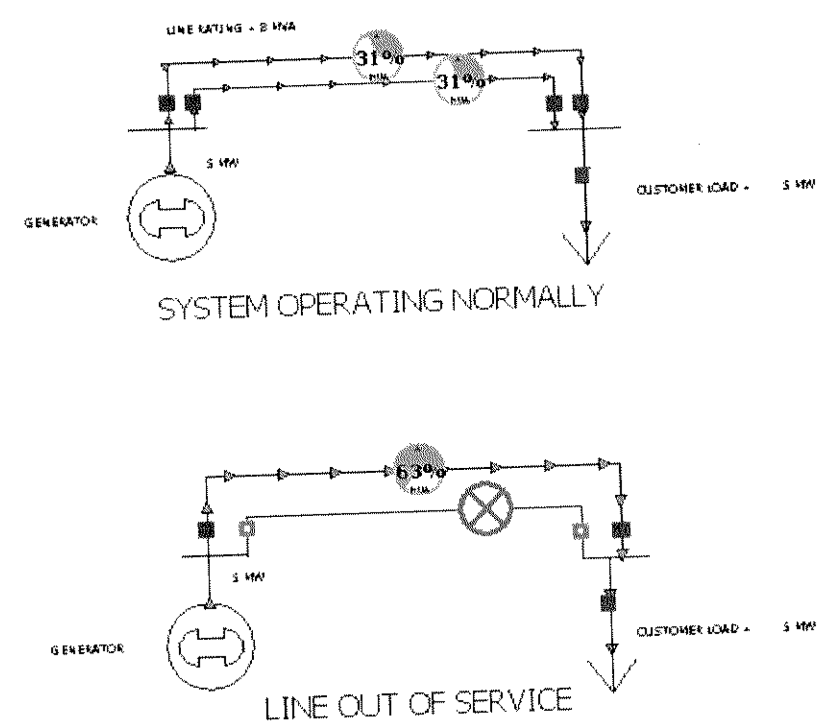
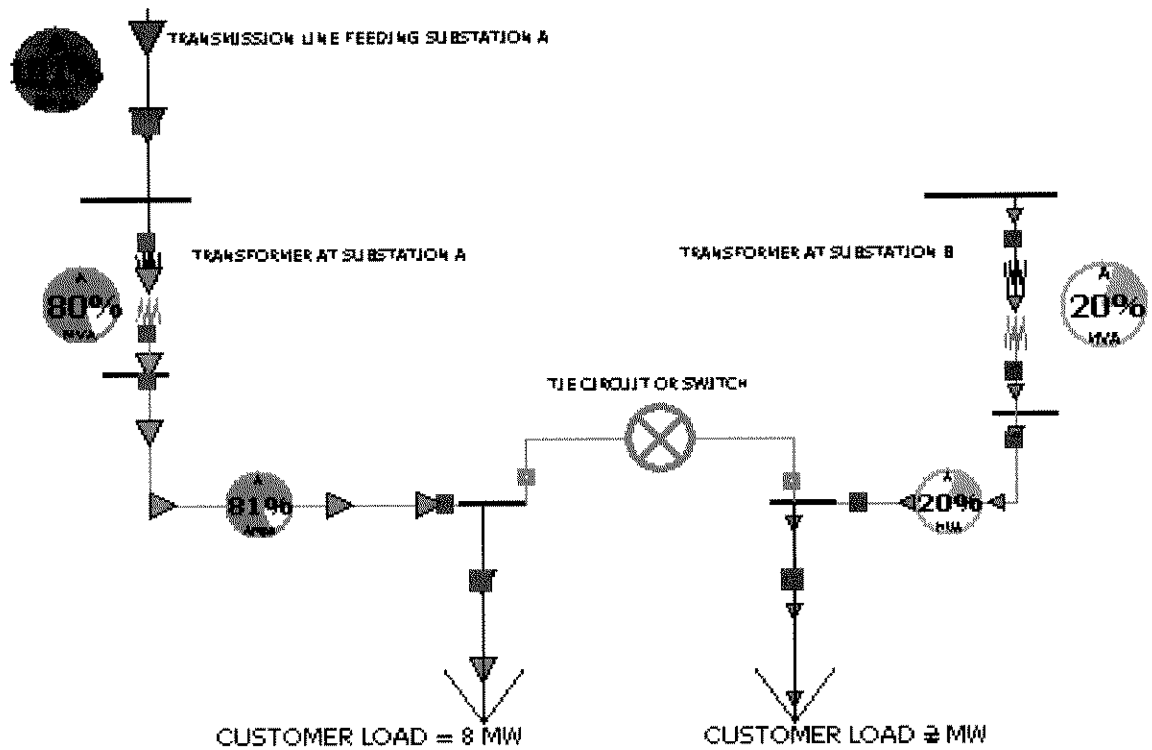


FIGURE 2 - MORE RELIABLE

CUSTOMER LOAD STILL SERVED

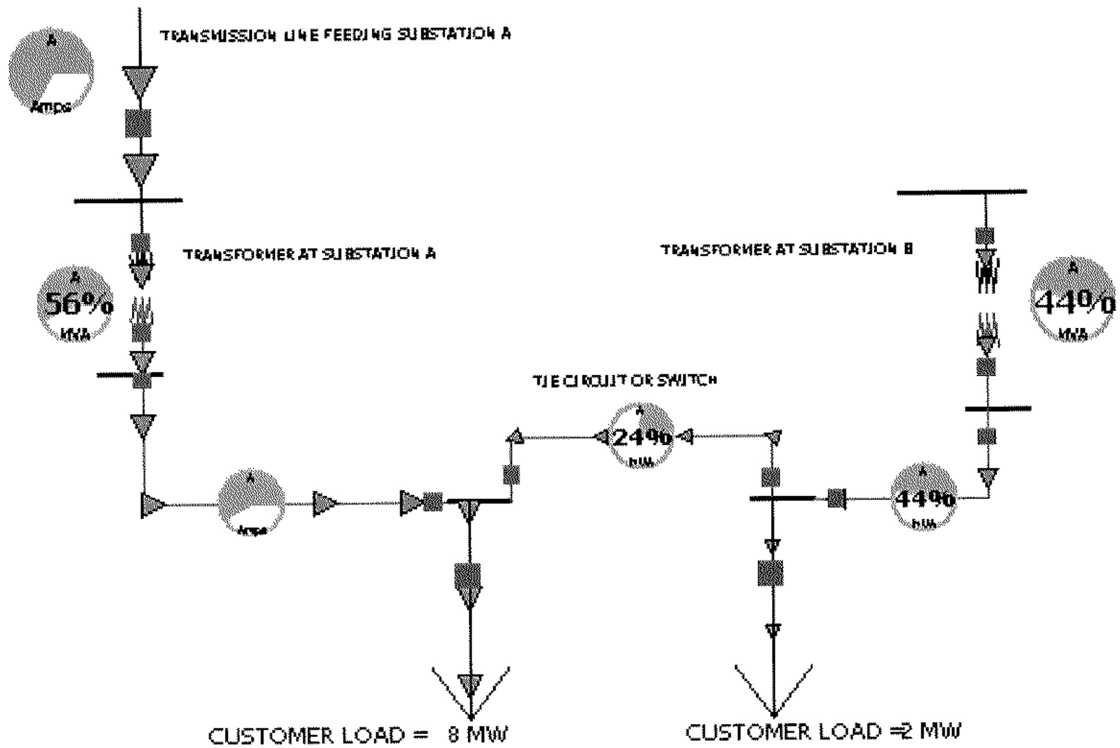
Example of System Reliability



SYSTEM NORMAL OPERATION

FIGURE 1 - POOR UTILIZATION

UNEQUAL LOAD DISTRIBUTION



TIE LINE/SWITCH CLOSED

FIGURE 2 - GOOD UTILIZATION

GOOD LOAD DISTRIBUTION

HECO - Existing 138 kV Transmission Line Utilization

From Name_Nominal kV	To Name_Nominal kV	Xfrmr	From MVA	To MVA	Lim A MVA	Lim B	% of MVA A	% of MVA B
ARCHER_138.00	KEWALO_138.00	No	8.5	6	199	382	4.3	2.2%
ARCHER_138.00	KEWALO_138.00	No	8.5	6	199	382	4.3	2.2%
ARCHER_138.00	IWILEI_138.00	No	53.8	52	274	390	19.6	13.8%
ARCHER_138.00	SCHOOL_138.00	No	47.3	45.4	274	390	17.3	12.1%
CEIP_138.00	AES_138.00	No	232.1	233.2	430	495	**54.2**	47.1%
CEIP_138.00	KAHE CD_138.00	No	18.9	18.8	430	495	4.4	3.8%
CEIP_138.00	KALAE_138.00	No	0	0	430	495	0	0.0%
CEIP_138.00	EWA NUI_138.00	No	160.7	158.9	364	491	44.1	32.7%
CEIP_138.00	KAHE CD_138.00	No	18.9	18.8	430	495	4.4	3.8%
HALAWA_138.00	IWILEI_138.00	No	82.9	82.6	331	385	25.1	21.5%
HALAWA_138.00	SCHOOL_138.00	No	99.8	99.3	331	385	30.1	25.9%
HALAWA_138.00	KOOLAU_138.00	No	94.9	94.4	342	392	27.7	24.2%
HALAWA_138.00	MAKALAPA_138.00	No	61.3	61.3	331	385	18.5	15.9%
HALAWA_138.00	KAHE AB_138.00	No	158.5	163.7	342	392	47.9	41.8%
HALAWA_138.00	KAHE AB_138.00	No	162.7	168.1	342	392	49.1	42.9%
HRRP_138.00	AES_138.00	No	46.1	46.1	123	142	37.5	32.5%
IWILEI_138.00	AIRPORT_138.00	No	104.5	105.1	331	385	31.7	27.3%
IWILEI_138.00	SCHOOL_138.00	No	8.7	8.8	331	385	**2.6**	2.3%
KAHE AB_138.00	WAIAU_138.00	No	129.1	126.7	342	392	37.8	32.9%
KAHE AB_138.00	WAHIAWA_138.00	No	132.3	129.4	342	392	38.7	33.8%
KAHE AB_138.00	KAHE CD_138.00	No	0	0	0	0	0	0.0%
KALAE_138.00	EWA NUI_138.00	No	186.5	183.6	364	491	51.2	38.0%
KALAE_138.00	AES_138.00	No	0.8	0.8	430	495	0.2	0.2%
KAMOKU_138.00	KEWALO_138.00	No	6.9	10.7	199	382	5.4	2.8%
KOOLAU_138.00	WAIAU_138.00	No	141.1	143.5	342	392	41.9	36.6%
KOOLAU_138.00	WAIAU_138.00	No	142.5	144.9	342	392	42.4	37.0%
KOOLAU_138.00	PUKELE_138.00	No	106.3	105.7	342	392	31.1	27.1%
KOOLAU_138.00	PUKELE_138.00	No	105.7	105.1	342	392	30.9	27.0%
MAKALAPA_138.00	AIRPORT_138.00	No	113.6	113.3	331	385	34.3	29.5%
MAKALAPA_138.00	WAIAU_138.00	No	168	169.3	430	495	39.4	34.2%
MAKALAPA_138.00	WAIAU_138.00	No	136.5	137.5	331	385	41.5	35.7%
PUKELE_138.00	KAMOKU_138.00	No	0	0	199	382	0	0.0%
WAHIAWA_138.00	WAIAU_138.00	No	17.9	16.5	342	392	5.2	4.6%
WAIAU_138.00	EWA NUI_138.00	No	146.2	147.5	364	491	40.5	30.0%
WAIAU_138.00	EWA NUI_138.00	No	147.9	149.3	364	491	41	30.4%
					Max Utilization:		54.2	47.1%
					Min. Utilization:		2.6	2.30%

Existing Substation Utilization - Normal Ratings

From Number	From Name	To Number	To Name	Status	Xfrmr	From MW	From Mvar	From MVA	Lim MVA	% of MVA Limit (Max)
4101	ARCH46A	100	ARCHER	Closed	Yes	-26.1	-10.6	28.2	83	35.5
4102	ARCH46B	100	ARCHER	Closed	Yes	-41.6	-12.6	43.5	83	55.4
4103	ARCH46C	100	ARCHER	Closed	Yes	-19.4	-8.7	21.2	83	26.4
4151	KOOL46A	150	KOOLAU	Closed	Yes	-53.9	4	54.1	80	68.1
4152	KOOL46B	150	KOOLAU	Closed	Yes	-23.7	4.8	24.2	80	30.3
4153	KOOL46C	150	KOOLAU	Closed	Yes	-44.2	5	44.5	80	55.6
4154	KOOL46D	150	KOOLAU	Closed	Yes	-44.2	3	44.3	80	55.6
2231	KAM25A	230	KAMOKU	Closed	Yes	-6.5	-2.4	6.9	50	14
2241	KEW25A	240	KEWALO	Closed	Yes	-3.5	-1.3	3.7	50	7.5
4171	PUKE46A	170	PUKELE	Closed	Yes	-61.5	-0.4	61.5	80	78.7
4172	PUKE46B	170	PUKELE	Closed	Yes	-56.1	-2.7	56.2	80	72.1
4173	PUKE46C	170	PUKELE	Closed	Yes	-33.4	-5.1	33.8	80	43.3
4174	PUKE46D	170	PUKELE	Closed	Yes	-56.1	2.7	56.2	80	71
4181	SCH 46A	180	SCHOOL	Closed	Yes	-30.2	-1.7	30.2	80	38.2
4182	SCH 46B	180	SCHOOL	Closed	Yes	-30.2	-2.5	30.3	80	38.4

HECO - Existing Substation Utilization - Normal Ratings

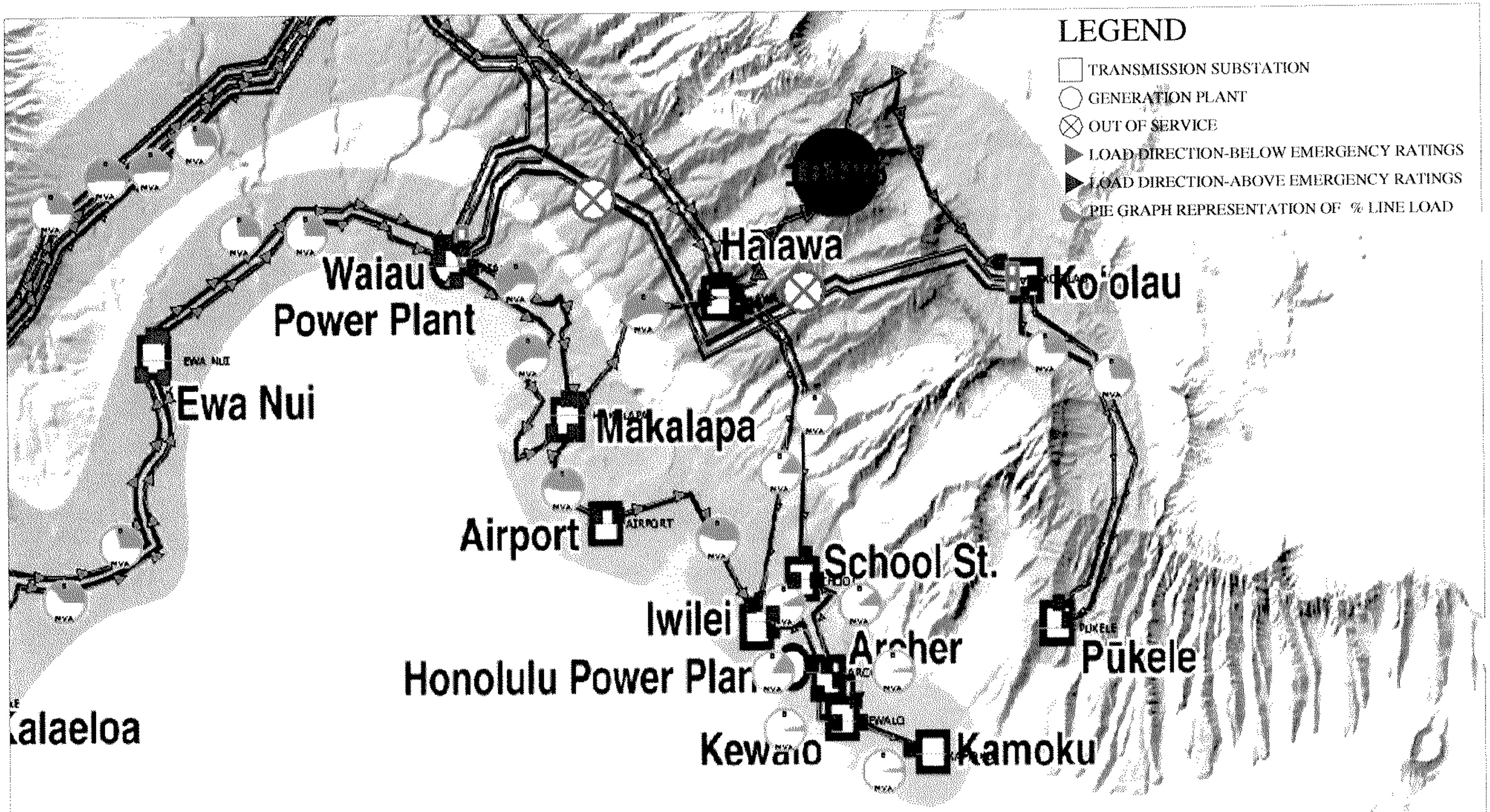
SUBSTATION UTILIZATION	MVA RATING	% USED	MVA LOADING	AVAILABLE MVA	AVAILABLE MVA (N-
ARCHER	249	37.31%	92.9	156.1	73.1
KOOLAU	320	52.22%	167.1	152.9	72.9
KAMOKU	50	13.80%	6.9	43.1	0
KEWALO	50	7.40%	3.7	46.3	0
PUKELE	320	64.91%	207.7	112.3	32.3
SCHOOL	160	37.81%	60.5	99.5	19.5
TOTAL:	**1149**	**46.89%**	**538.8**	**610.2**	**197.8**

Existing Substation Utilization - Emergency Ratings

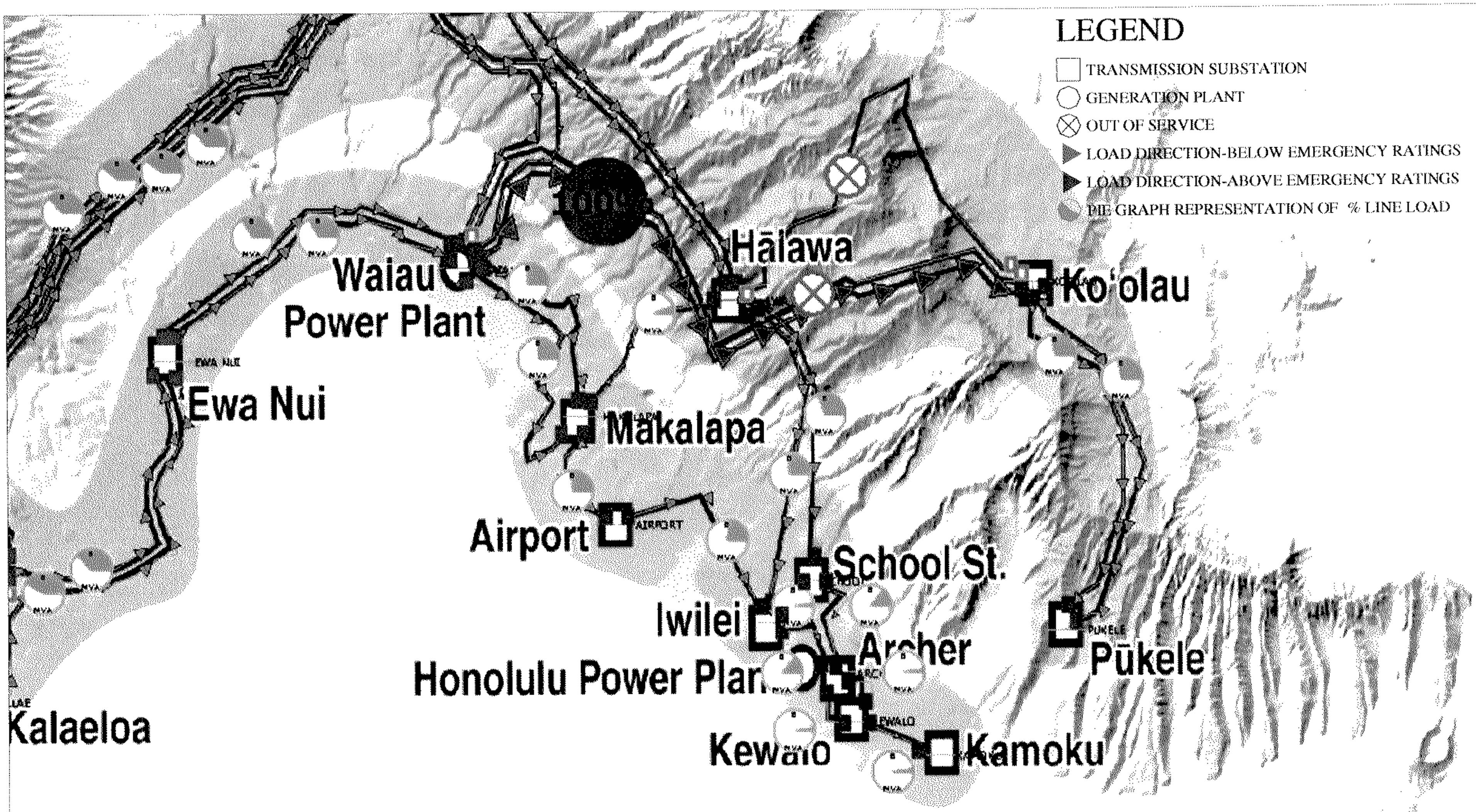
From Number	From Name	To Number	To Name	Status	Xfmr	From MW	From Mvar	From MVA	Lim MVA	% of MVA Limit (Max)
4101	ARCH46A	100	ARCHER	Closed	Yes	-26.1	-10.6	28.2	110	26.7
4102	ARCH46B	100	ARCHER	Closed	Yes	-41.6	-12.6	43.5	110	41.8
4103	ARCH46C	100	ARCHER	Closed	Yes	-19.4	-8.7	21.2	110	19.9
4151	KOOL46A	150	KOOLAU	Closed	Yes	-53.9	4	54.1	106	51.4
4152	KOOL46B	150	KOOLAU	Closed	Yes	-23.7	4.8	24.2	106	22.8
4153	KOOL46C	150	KOOLAU	Closed	Yes	-44.2	5	44.5	106	42
4154	KOOL46D	150	KOOLAU	Closed	Yes	-44.2	3	44.3	106	41.9
2231	KAM25A	230	KAMOKU	Closed	Yes	-6.5	-2.4	6.9	60	11.6
2241	KEW25A	240	KEWALO	Closed	Yes	-3.5	-1.3	3.7	60	6.2
4171	PUKE46A	170	PUKELE	Closed	Yes	-61.5	-0.4	61.5	106	59.4
4172	PUKE46B	170	PUKELE	Closed	Yes	-56.1	-2.7	56.2	106	54.4
4173	PUKE46C	170	PUKELE	Closed	Yes	-33.4	-5.1	33.8	106	32.6
4174	PUKE46D	170	PUKELE	Closed	Yes	-56.1	2.7	56.2	106	53.6
4181	SCH 46A	180	SCHOOL	Closed	Yes	-30.2	-1.7	30.2	106	28.8
4182	SCH 46B	180	SCHOOL	Closed	Yes	-30.2	-2.5	30.3	106	28.9

HECO - Existing Substation Utilization - Emergency Ratings

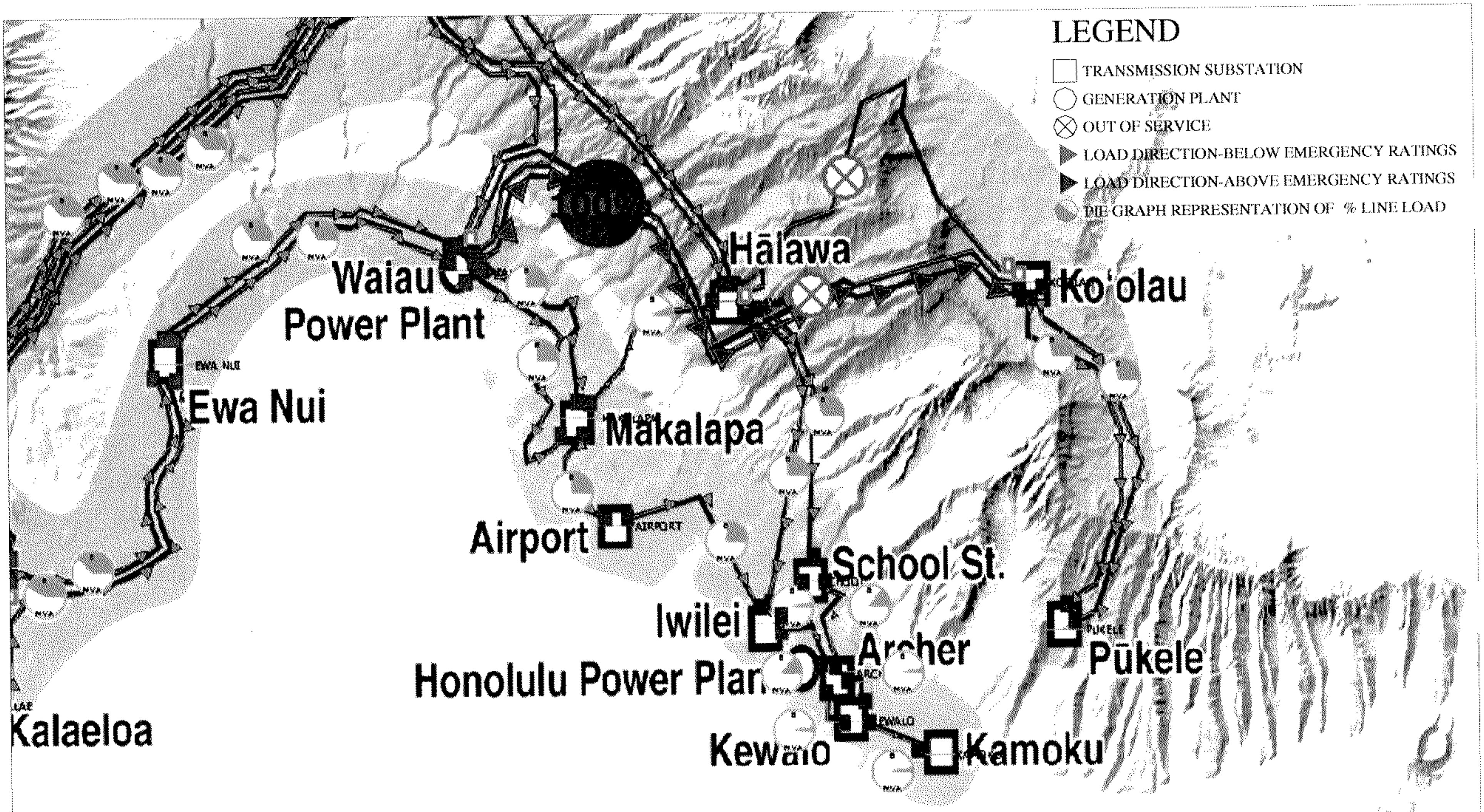
SUBSTATION UTILIZATION	MVA RATING	% USED	MVA LOADING	AVAILABLE MVA	AVAILABLE MVA (N-
ARCHER	330	28.15%	92.9	237.1	127.1
KOOLAU	424	39.41%	167.1	256.9	150.9
KAMOKU	60	11.50%	6.9	53.1	0
KEWALO	60	6.17%	3.7	56.3	0
PUKELE	424	48.99%	207.7	216.3	110.3
SCHOOL	212	28.54%	60.5	151.5	45.5
TOTAL:	**1510**	**35.68%**	**538.8**	**971.2**	**433.8**



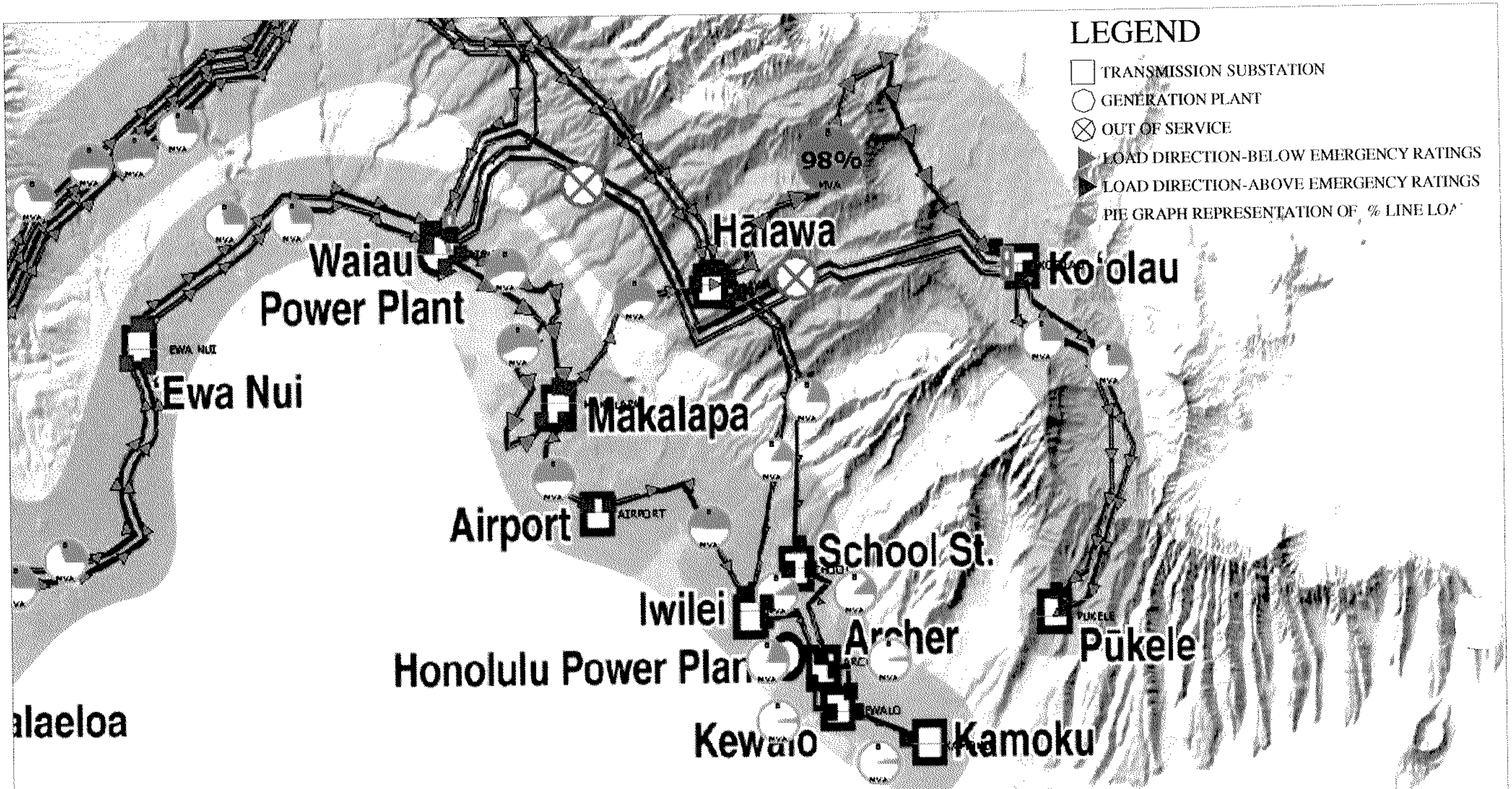
KOOLAU/PUKELE OVERLOAD SITUATION - 2007
(WAIAU-KOOLAU CIRCUITS 1&2 OUT OF SERVICE)



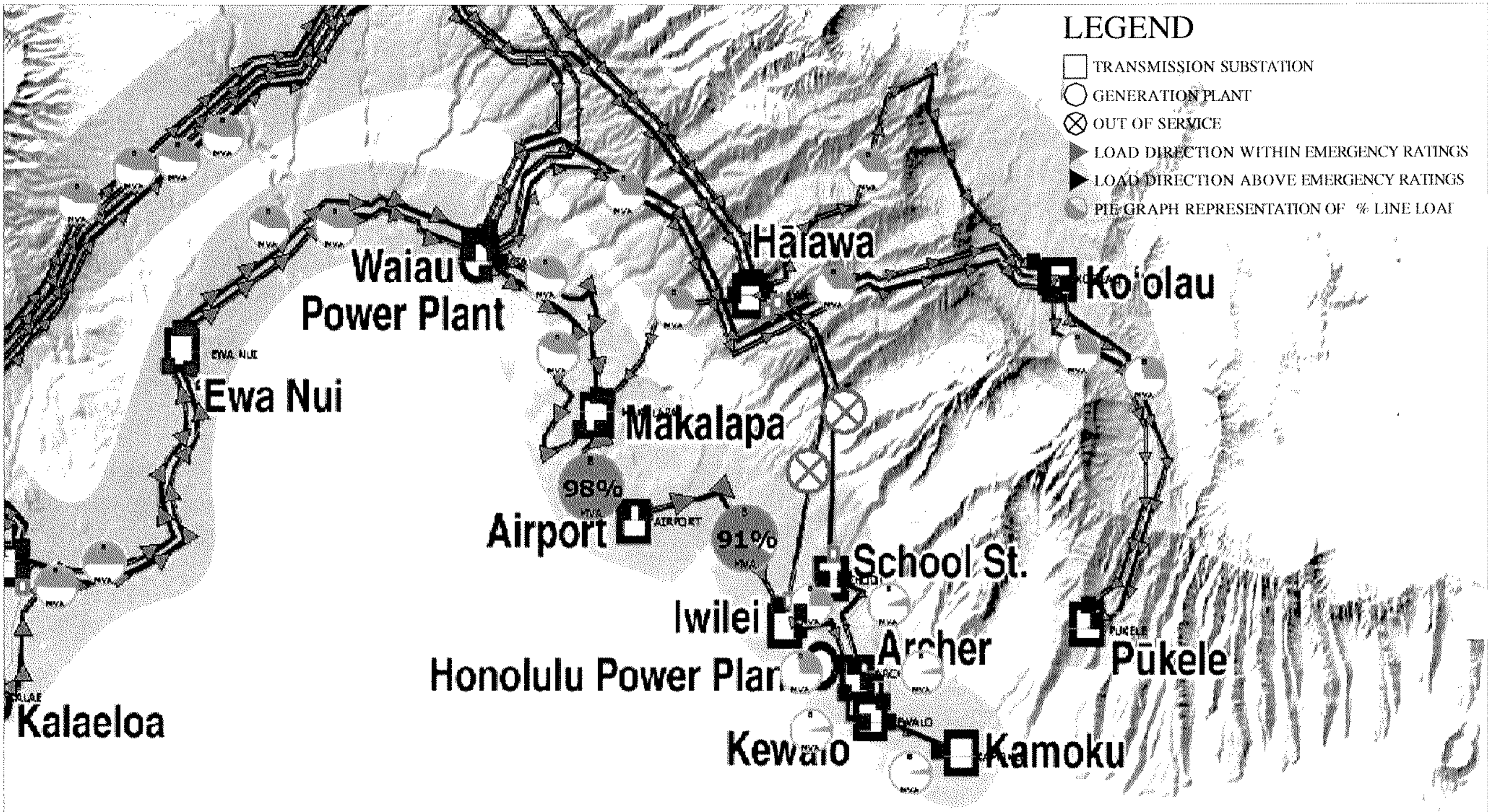
KOOLAU/PUKELE OVERLOAD SITUATION - 2012
(WAIAU-KOOLAU CIRCUIT 1&HALAWA-KOOLAU LINES OUT OF SERVICE)



KOOLAU/PUKELE OVERLOAD SITUATION - 2012
(WAIAU-KOOLAU CIRCUIT 1&HALAWA-KOOLAU LINES OUT OF SERVICE)



KOOLAU/PUKELE OVERLOAD SITUATION - 2012
MINIMUM (23.1 MVA) LOAD TRANSFERRED FROM PUKELE TO DOWNTOWN
(WAIAU-KOOLAU CIRCUITS 1&2 OUT OF SERVICE)



DOWNTOWN OVERLOAD SITUATION - 2022
(HALAWA-IWILEI AND HALAWA-SCHOOL ST. LINES OUT OF SERVICE)

(Kamoku 46kV Underground Alternative - Expanded)
Taken From HECO Load Flow Case: LS2007DA

2007	SUBSTATION UTILIZATION - NORMAL RATINGS	MVA RATING	% USED	MVA LOADING	AVAILABLE MVA	AVAILABLE MVA (N-1)
	ARCHER	249	56.3%	140.2	108.8	25.8
	KOOLAU	320	52.3%	167.3	152.7	72.7
	KAMOKU	130	47.3%	61.5	68.5	0
	KEWALO	50	8.0%	4	46	0
	PUKELE	320	38.8%	124.3	195.7	115.7
	SCHOOL	160	38.9%	62.3	97.7	17.7
	TOTAL:	1229	45.5%	559.6	669.4	231.9

2007	SUBSTATION UTILIZATION - EMERGENCY RATINGS	MVA RATING	% USED	MVA LOADING	AVAILABLE MVA	AVAILABLE MVA (N-1)
	ARCHER	330	42.5%	140.2	189.8	79.8
	KOOLAU	424	39.4%	167.2	256.8	150.8
	KAMOKU	166	37.0%	61.5	104.5	0
	KEWALO	60	6.7%	4	56	0
	PUKELE	424	29.3%	124.3	299.7	193.7
	SCHOOL	212	29.4%	62.3	149.7	43.7
	TOTAL:	1616	34.6%	559.5	1056.5	468

2012 EOTP Transformer Utilization
(Kamoku 46kV Underground Alternative - Expanded)
Taken From HECO Load Flow Case: LS2012DC

2012	SUBSTATION UTILIZATION - NORMAL RATINGS	MVA RATING	% USED	MVA LOADING	AVAILABLE MVA	AVAILABLE MVA (N-1)
	ARCHER	332	44.2%	146.7	185.3	102.3
	KOOLAU	320	54.4%	174.2	146	66
	KAMOKU	130	49.4%	64.2	65.8	0
	KEWALO	50	8.4%	4.2	45.8	0
	PUKELE	320	40.3%	129	191	111
	SCHOOL	160	42.1%	67.3	126.4	12.7
	TOTAL:	1312	44.6%	585.6	760.3	292

2012	SUBSTATION UTILIZATION - EMERGENCY RATINGS	MVA RATING	% USED	MVA LOADING	AVAILABLE MVA	AVAILABLE MVA (N-1)
	ARCHER	440	33.3%	146.7	293.3	183.3
	KOOLAU	424	41.1%	174.2	249.8	143.8
	KAMOKU	166	38.7%	64.2	101.8	0
	KEWALO	60	7.0%	4.2	55.8	0
	PUKELE	424	30.4%	129	295	189
	SCHOOL	212	31.7%	67.3	144.7	38.7
	TOTAL:	1726	33.9%	585.6	1140.4	554.8

2017 EOTP Transformer Utilization
(Kamoku 46kV Underground Alternative - Expanded)
Taken From HECO Load Flow Case: LS2017DC

2017	SUBSTATION UTILIZATION - NORMAL RATINGS	MVA RATING	% USED	MVA LOADING	AVAILABLE MVA	AVAILABLE MVA (N-1)
	ARCHER	332	42.8%	142.2	189.8	106.8
	KOOLAU	320	56.7%	181.3	138.7	58.7
	KAMOKU	130	52.4%	68.1	61.9	-18.1
	KEWALO	130	4.7%	6.1	80	0
	PUKELE	320	41.4%	132.5	187.5	107.5
	SCHOOL	160	42.1%	67.3	116.5	36.5
	TOTAL:	1392	42.9%	597.5	774.4	291.4

2017	SUBSTATION UTILIZATION - EMERGENCY RATINGS	MVA RATING	% USED	MVA LOADING	AVAILABLE MVA	AVAILABLE MVA (N-1)
	ARCHER	440	32.3%	142.2	297.8	187.8
	KOOLAU	424	42.8%	181.3	242.2	136.2
	KAMOKU	166	41.0%	68.1	97.9	0
	KEWALO	166	3.7%	6.1	106	0
	PUKELE	424	31.3%	132.5	291.5	185.5
	SCHOOL	212	31.7%	67.3	125.2	19.2
	TOTAL:	1832	32.6%	597.5	1160.6	528.7

2022 EOTP Transformer Utilization
(Kamoku 46kV Underground Alternative - Expanded)
Taken From HECO Load Flow Case: LS2022DB

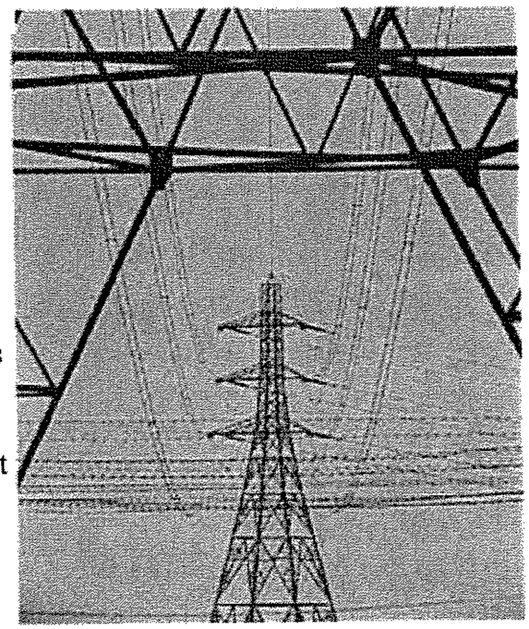
2022	SUBSTATION UTILIZATION - NORMAL RATINGS	MVA RATING	% USED	MVA LOADING	AVAILABLE MVA	AVAILABLE MVA (N-1)
	ARCHER	332	43.4%	144.2	187.8	104.8
	KOOLAU	320	58.9%	188.4	131.6	51.6
	KAMOKU	130	55.9%	72.7	57.3	0
	KEWALO	130	8.0%	10.4	119.6	0
	PUKELE	320	41.9%	134	186	106
	SCHOOL	160	49.3%	78.9	81.1	1.1
	TOTAL:	1392	45.2%	628.6	763.4	263.5

2022	SUBSTATION UTILIZATION - EMERGENCY RATINGS	MVA RATING	% USED	MVA LOADING	AVAILABLE MVA	AVAILABLE MVA (N-1)
	ARCHER	440	32.8%	144.2	295.8	185.8
	KOOLAU	424	44.4%	188.4	235.6	129.6
	KAMOKU	166	43.8%	72.7	93.3	0
	KEWALO	166	6.3%	10.4	155.6	0
	PUKELE	424	31.6%	134	290	184
	SCHOOL	212	37.2%	78.9	133.1	27.1
	TOTAL:	1832	34.3%	628.6	1203.4	526.5

The Unruly Power Grid

Advanced mathematical modeling suggests that big blackouts are inevitable

By Peter Fairley



Thanks to an authoritative U.S.-Canada report, we now know that negligence by a utility in Ohio and lax oversight by a rookie regulator precipitated the blackout that darkened much of the North American upper Midwest and Northeast a year ago. Paradoxically, however, when the same remarkable event is seen in a wider historical and statistical perspective, it is no less natural than a sizable earthquake in California. Major outages occurred in the western U.S. grid just eight years ago. And last fall, electric power systems collapsed n Denmark, Italy, and the United Kingdom within weeks or months of the U.S. blackout.

The 14 August 2003 blackout may have been the largest in history, zapping more total wattage and affecting more customers than any before, but if history is any guide, it won't be the last. "These kinds of outages are consistent with historical statistics, and they'll keep happening," says John Doyle, professor of control and dynamical systems, electrical engineering, and bioengineering at the California Institute of Technology in Pasadena. "I would have said this one was overdue."

"We will have major failures," agrees IEEE Fellow Vijay Vittal, an electrical engineering professor at Iowa State University in Ames, who is an expert on power system dynamics and control. "There is no doubt about that."

The numbers on blackouts bear out this fatalism. Extrapolating from the small outages that occur frequently, one might expect a large power grid to collapse only once in, say, 5000 years. But between 1984 (when North American utilities began to systematically report blackouts) and 2000, utilities logged 11 outages affecting more than 4000 megawatts—making the probability of any one outage 325 times greater than mathematicians would have expected. Thus, statistically speaking, the blackout on 14 August, which, according to the U.S. Department of Energy, cost between US $4 billion and $6 billion, was no anomaly [see graph, "Only Too Likely"].

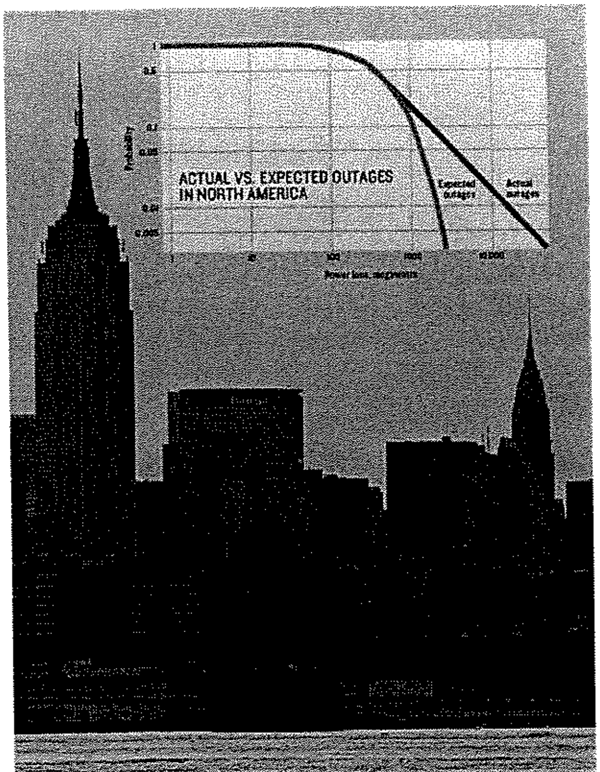
In the mid-1990s—well before FirstEnergy in Akron, Ohio, got sloppy with its tree-trimming and monitoring systems last summer—mathematicians, engineers, and physicists set out to explain the statistical overabundance of big blackouts. Two distinct models emerged, based on two general theories of systems failure.

One, an optimization model, championed by Caltech's Doyle, presumes that power engineers make conscious and rational choices to focus resources on preventing smaller and more common disturbances on the lines; large blackouts occur because the grid isn't forcefully engineered to prevent them. The competing explanation, hatched by a team connected with the Oak Ridge National Laboratory in Tennessee, views blackouts as a surprisingly constructive force in an unconscious feedback loop that operates over years or decades. Blackouts spur investments to strengthen overloaded power systems, periodically counterbalancing pressures to maximize return on investment and deliver electricity at the lowest possible cost.

Which of these models better explains the mechanism behind large blackouts is a matter of intense—sometimes even bitter—debate. But their proponents agree on one thing: the brave, can-do recommendations of the U.S.-Canada task force report won't eliminate large blackouts, if either conscious optimization or unconscious feedback sets up power systems to fail, then large cascading blackouts are natural facets of the power grid. Stopping them will require that engineers fundamentally change the way they operate the power system. "I don't think there are simple policy fixes," says Doyle.

Of course, the very idea of accepting the inevitability of blackouts is utterly rejected by utility officials and politicians. Certainly the mainstream view among power system engineers continues to be that the answer to reliability problems is to make the grids more robust physically, improve simulation techniques and computerized real-time controls, and improve regulation. What the systems theorists suggest is that even if all that is done and done well— as, of course, it should be—the really big outages still will happen more often than they should.

THE SUSPICION THAT NASTY SURPRISES lurk in the inner workings of power grids began to take shape in the early 1980s with the growth of research into nonlinear systems, a field that became known as chaos theory. The term was a misnomer, for chaos experts were describing layers of order hidden in the apparent disorder of everything from turbulent fluids to celestial mechanics.



ONLY TOO LIKELY: Work at Carnegie Mellon University shows that the likelihood of large failures is greater than one would expect on the basis of extrapolations from small failures. The brown curve is fit to actual outages that affected more than 500 megawatts of power; the blue curve is an exponential distribution fit to failures smaller than 800 MW. The silhouette in the background is of the New York City skyline on the evening of 14 August 2003.
PHOTO: CHIP EAST/REUTERS

In November 1982, a pair of mathematicians made one of the first attempts to apply chaos theory to power grids. Nancy Kopell, at that time a nonlinear dynamics expert at Northeastern University in Boston, and Robert Washburn, a mathematician and chief scientist with Alphatech Inc., a Boston-based systems-engineering consulting firm, were novices to electrical power systems. But what they found revolutionized thinking about power system behavior.

Kopell and Washburn's insight was to recognize that the differential equations used to describe the dynamic interactions of power generators on a grid—known as swing equations, which remain a critical tool for power system modelers—resemble the equations developed by the 19th-century mathematician Henri Poincaré to describe the gravitational interplay among celestial bodies. Adapting Poincaré's techniques, Kopell and Washburn managed to model more accurately the behavior of a simple grid with three generators—two large and one small.

The results were analogous to what Poincaré found when he considered the behavior of two large bodies and a third that is relatively small. In that case, tiny shifts in the relative position and motion of the large bodies dramatically altered the trajectory of the third. In modern parlance, we'd say that Poincaré's system is chaotic. Kopell and Washburn observed the same behavior in their three-machine power grid in response to simulated faults on the lines: tweak the operating parameters of the large generators just slightly, and a previously stable grid would suddenly run away.

By the early 1990s, power systems experts were exploiting the techniques and discovering chaotic behavior in more complex models. Power systems expert James Thorp, an engineering professor at Cornell University, plotted the results from models with dozens of generators and lines, producing fractal patterns that are the hallmark of chaos mathematics [see fractal image, "Random Patterns"]. Yet these models still seemed too simplistic to be applicable to real-life power grid situations.

"The fact that you see transient chaos was enough to convince people that the power system is much more complicated than we might have imagined, but there was not an obvious connection to blackouts," says Thorp.

The connection between chaos and blackouts began to tighten when researchers started to work with actual blackout data. In the mid-1990s, Doyle, at Caltech, began to mine data on blackouts that had been collected since 1984 by the North American Electric Reliability Council, the organization in Princeton, N.J., that promotes voluntary standards for the electric power industry. A team consisting of Benjamin A. Carreras, an expert in chaos theory at Oak Ridge National Laboratory; David Newman, now a professor of physics at the University of Alaska; and Ian Dobson, a University of Wisconsin professor of electrical and computer engineering and an expert on chaos and power grids, stumbled on the same data in 1997.

What Doyle and the Carreras-Newman-Dobson group found amazed them. Plotting the logs of the frequency of blackouts versus their magnitude, they observed that the frequency of large blackouts was much higher than they expected. Rather than falling off sharply to fit the bell curve produced by a Gaussian, or normal, distribution, the frequency of blackouts fell off much more slowly. The curve fit what is called a power law—which refers not to the power in a circuit but to the fact that the probability of a blackout is related to its magnitude by some constant exponent.

The result excited the system-dynamics and chaos experts because such power-law frequency distributions are a signature of complex, chaotic systems in which the interplay of the components leads to surprising outcomes. Other examples of complicated events that seem to occur with similar regularity are earthquakes, forest fires, and dam failures. Systems analysts think they know something about the dynamics that lead to such events; so the discovery of a similar probability distribution gave them hope that they could learn a thing or two about blackouts. "We said there must be something about the way the grid is managed that makes all these points want to be on a line," says Carreras. "They are not jumping around. It's as if there is a physical law there."

One thing they knew for sure was that phenomena that fit such distributions tend to occur with remarkable consistency. Devastating earthquakes may be hard to predict, but we know when one is overdue. So when the 14 August blackout struck, the systems theorists raced to their plots to see if this additional piece of data fit the pattern.

Thorp went straight back to his office when the lights came back on at Cornell in upstate New York, took one of Doyle's plots, and extended the curve farther out to the right, from blackouts affecting millions of customers to blackouts affecting tens of millions. The curve predicted that an outage of the scope seen a year ago should occur, on average, every 35 years. The result was chilling, for it had been 38 years since the last cascading outage on the Eastern interconnection (the transmission system connecting the eastern U.S. seaboard, the Plains states, and the eastern Canadian provinces). That outage, on 9 November 1965, blacked out 30 million people in the northeastern United States and Canada.

FOR SYSTEMS THEORISTS like Doyle and Carreras, the first message of their eerily smooth distribution curves is clear: big blackouts are a natural product of the power grid. The culprits that get blamed for each blackout—lax tree trimming, operators who make bad decisions—are actors in a bigger drama, their failings mere triggers for disasters that in some strange ways are predestined. In this systems-level view, massive blackouts are just as inevitable as the megaquake that will one day level much of Tokyo. Just the same, accounting for that inevitability is a contentious exercise.

To date, Carreras, Dobson, and Newman's explanation for the curves—the feedback model— is the most vivid and, arguably, the most sophisticated. Computer simulations to test this model rack as many as 400 power lines and 30 or so generators and run for the equivalent of 250 years. The results are uncannily similar to the historical record. Carreras and his colleagues were inspired by a simple physical system: the growth of sand piles. In the 1990s, physicists studying sand piles mathematically modeled a phenomenon long noticed by children playing on beaches. As you keep piling on sand, a part suddenly begins to collapse, and when you try to fix the castle by piling on more sand, one side suddenly gives way. Seen mathematically, the pile has reached a critical point where its behavior has become chaotic; avalanches become frequent, and their magnitude fits a power-law curve.

Carreras, Dobson, and Newman wondered if power grids might approach the same kind of critical points as elements are added and power flows increase. They imagined that economic forces and engineering practices seeking to minimize costs and maximize returns on investment in transmission equipment could push system operators to accept higher and higher power levels on their systems, setting the system up for a fall. Feedback from angry politicians and customers would then prompt improvements in the grid, such as construction of additional lines, replacement of faulty relays, or distributed deployment of generators. The short-term result, of course, is to take the system out of its precarious state. But by increasing the system's stability, the improvements would also initiate another cycle of loading.

"You go up near criticality and then you back off a bit because you experience blackouts," explains Dobson. "It's the right thing to do, but the effect is to increase the capability of the system relative to the loading." Since the forces that squeeze more power onto the lines are all present—the pressure to minimize costs and maximize returns—the system is destined to run back to criticality.

TO TEST THIS THEORY, Dobson and his colleagues took a standard electric power flow model—the sort employed by system planners—and set it in motion, using workstations for the simulation. First, they programmed the model to boost the total load on the lines by 2 percent per year (the North American average) and recalculate the resulting power flows daily. Next, hey told the system to knock out a line occasionally, simulating the lightning strikes and other random events that afflict real power lines. In some cases, the recalculated flows would overload neighboring lines, simulating a cascading failure. Finally, they stipulated in the design that every time a blackout occurs, the model "upgrades" the lines involved by boosting their rated capacity.

The resulting distribution of blackouts is statistically equivalent to the post-1984 blackout data collected by the North American Electric Reliability Council. "The system itself finds its own equilibrium near criticality," says Dobson.

Doyle couldn't disagree more. He says the notion of opposing forces pushing power grids into a critical state is so much hocus-pocus, the engineering equivalent of creationism. (Doyle also questions Carreras, Dobson, and Newman's statistical methodology—a disagreement he is pursuing as a peer reviewer on their papers.) Plus, Doyle's less-detailed optimization model for engineering failures can reproduce the historical distribution of large blackouts just as well as the feedback model (better if his arguments on statistical methodology win the day).

And yet even Doyle acknowledges that these two approaches send the same bottom-line message to system planners: major blackouts are a byproduct of a complex system and only fundamental change in the system can extinguish them.

If people like Doyle and Dobson sound cautionary about the prospects for blackout prevention, there is a third school of thought that is downright resigned. Its views have been articulated by a group at Carnegie Mellon University in Pittsburgh and its Electricity Industry Center. Its members include Sarosh N. Talukdar, a power engineer and electrical and computer engineering professor; Jay Apt, an engineering and public policy professor; and Lester B. Lave, a risk assessment expert and economics professor.

In a startling thought piece, "Cascading Failures: Survival Versus Prevention," published in The Electricity Journal in November 2003, the Carnegie Mellon team argues that if blackouts are as hard to predict and prevent as tsunamis and earthquakes, we should make it our business to be prepared. They argue that the question is not how to prevent blackouts, but how to survive them.

This pragmatic survival thesis begins with the assertion that complex systems—be they power grids or space shuttles—are prone to failure and well-intentioned efforts at prevention can backfire. In the feedback model, for instance, increasing the rating of individual power lines often increases the frequency of large cascading failures, much as the suppression of individual forest fires eventually leads to major conflagrations.

The Carnegie Mellon group argues that the problem with preventing grid failures runs even deeper. The real problem, they say, is the impossibility of testing a potential fix to confirm that it actually decreases the risk of failure. Crash-testing a grid the way one crash-tests a new car is obviously not an option. And the only alternative, simulation, is beyond the reach of current technology for a system as complex as the Eastern Interconnection—a system with thousands of generators and tens of thousands of power lines and transformers. Fully assessing just one contingency on the Eastern Interconnection means accounting for more than a billion constraints. Add nonlinear behavior of the sort Thorp models, and the differential equations become unsolvable. "You couldn't get a computer big enough on this planet to go do that," says Apt.

Some of the world's experts in power system dynamics and modeling acknowledge the problem. Experts in western North America, stung by the summer blackouts of 1996 that shut down grids from British Columbia to Mexico's Baja Peninsula, have done more to measure and simulate grid behavior than most. And yet their models regularly come up short, dangerously overestimating the Western Interconnection's ability to damp oscillations during a major outage. "Our simulations are not always realistic," concedes modeling expert Carson Taylor, principal engineer for transmission with the Bonneville Power Administration in Portland, Ore.

Instead of waiting for better dynamic models, the Carnegie Mellon group says that now is the time to begin accommodating blackouts, to do more to empower critical consumers and infrastructure to ride through them. "When you build stuff, it's going to break," says Apt. "The question is: what are the cost-effective things you can do to minimize the consequences?" His answer is: "A lot more than we're doing."

One cost-effective example identified by Apt and his colleagues is to equip traffic signals with energy-efficient light-emitting diodes backed up by batteries [see sidebar, "Better Backups for John Q. Public"]. Such gridlock-defying lights could eliminate a leading cause of death during blackouts while keeping emergency routes clear. And how about elevators that automatically ease down to the nearest floor upon losing power? "Our guess is that if you designed that [capability] into the elevator system originally, it would be all but free," says Lave.

The systems modelers see one more big benefit from greater preparedness: in the strange world of complex systems and unintended consequences, preparing for blackouts might just reduce the frequency of big ones. Carreras posits that utilities might be more willing to disconnect some customers deliberately, or "shed load," when the system is stressed if their customers were prepared for outages. According to the U.S.-Canada report, such load shedding would have confined the 14 August blackout to small patches of Ohio.

Carreras says that simply allowing more small blackouts could have the same effect. He points to the forest fire analogy, where hyperactive firefighting has enabled forests to age and accumulate fuel, laying the foundation for the major conflagrations that have become a summer staple in the western United States. In forest fire models, he says, the simulated firefighters can be programmed to be lazy, and the result is paradoxical: "You lose trees, but you never lose the whole forest," says Carreras.

ACCEPTING THE INEVITABILITY OF BLACKOUTS is akin to accepting defeat for many power industry leaders. But considering the deliberate weakening of the power grid is downright treasonous. For the record, Carreras, who is employed by the U.S. Department of Energy, says he does not give advice to policymakers, certainly not about purposely weakening the grid. "Nobody wants to hear that," confides Carreras. "If I say that publicly, people will kill me." So it is not at all surprising that the authors of the U.S.-Canada task force report pay no heed to the possibility that their recommendations to strengthen the grid could have under whelming impact or unintended consequences.

James W. Glotfelty, director of the U.S. Department of Energy's Office of Electric Transmission and Distribution and a key liaison between the technical and political players on the task force, s unapologetic. He dismisses all the studies that conclude large blackouts are not preventable. His view: "Trim your trees, train your operators, and ensure that your systems work, and the risk of a blackout is greatly reduced. Period." He similarly rejects the Carnegie Mellon team's argument that the limitations of modeling preclude our knowing how to prevent blackouts and that consumers and governments should therefore focus more resources on surviving them.

"If we have the intellectual and computing capability to model nuclear weapons, then we have the ability to do this, too," says Glotfelty. Clark W. Gellings, vice president for power delivery and marketing at the Electric Power Research Institute in Palo Alto, Calif., is equally dismissive of the systems theories. For example, he calls the comparison to firefighting "nonsense." At the same time, neither claims to have spent much time pondering these ideas. "They haven't hit the mainstream yet," says Gellings.

And yet Gellings agrees strongly with one of the ideas: that the grid needs fundamental change. "I agree with the conclusion that you have to change the basic operation of the grid to prevent blackouts." Many senior power engineers are frustrated by the current operation of the grid and are hatching ambitious plans for a major overhaul, he adds. The Electric Power Research Institute has championed the use of electronic power control devices that can massage and control ac power flows—a radical change from today's grid, where only the geography of supply and demand determine how electricity flows through the grid. Some advocate a wholesale shift toward the use of electronically controlled dc power lines to boost capacity for long-range power transfers and simultaneously act as "firebreaks" to contain disturbances cascading along ac power lines.

The problem with these visions for technological redesign is that large-scale investment in transmission is a fantasy in today's turbulent power industry. "If you were silly enough to think about investing in transmission, we would tell you that we don't have any idea how you're going to get reimbursed or how much you're going to get reimbursed," says Lave.

The more immediate problem may be the industry's under investment in R&D. It spends just 0.3 percent of revenues on R&D, one of the lowest rates for any industrial sector. "We're beat out easily by the pet food manufacturers," laments Dobson. The comparison between U.S. Department of Energy spending on nuclear weapons research and power system design is less flattering by a long shot.

The first step toward recovery is accepting that one has a problem. The U.S.-Canada report, for all its technical merit, pandered to a desire for quick fixes, perpetuating a sense of denial about blackouts. "I keep hearing claims that we are going to develop technologies to suppress all the blackouts and I find the whole position a bit laughable," says Carreras. "There may be no solution to all of our problems. We don't want to look at that."

Kopell, one of the mathematicians who first applied chaos theory to grid behavior, now directs a biodynamics center at Boston University, having previously won a MacArthur fellowship to study brain neurology. But she still thinks that the power industry and its political supporters need to take a longer view of blackout research and to think more deeply about the grid's propensity for non-intuitive behavior. Call it what you will—systems dynamics, chaos theory, or criticality analysis—Kopell says we're going to need more of it. As she put it, "This work won't immediately give an answer to the problem, but it certainly shows that simple thinking about it isn't adequate."

ELECTRIC SYSTEM DEFINITIONS AND TERMINOLOGY

"**Transmission System**" – HECO operates a power "transmission system" at a voltage of 138,000 volts (138 kV). A transmission system is utilized to transmit power from generation locations to transmission substations (or service areas/load centers). HECO also includes some 46 kV sub-transmission lines in their transmission system. Transmission lines are placed on wood and/or steel structures that are utilized to support aluminum conductors, which carry the electrical power to load centers. See CA-101 for a depiction of HECO's transmission system.

"**Sub-transmission System**" – Once Power is transmitted from generating stations to transmission substations, HECO "steps down" the 138 kV system to 46 kV, which is referred to as the sub-transmission system. From transmission substations, numerous sub-transmission lines (primarily overhead and some newer underground) emanate from the transmission substations to hundreds of distribution substations, where the distribution system is utilized to deliver power to individual customers. CA-102 shows HECO's 46 kV sub-transmission system in and around the Pukele Substation service area. This figure was provided by HECO in response to CA-IR-32 and is Figure 2-4 from the Kamoku-Pukele Revised Final EIS.

"**Distribution System**" – At distribution substations fed from sub-transmission lines, HECO once again "steps down" voltage levels from 46 kV to various distribution levels (13.8 kV, 11 kV, 4 kV). From the distribution substations, numerous lines distribute the power to individual customers. There is not an exhibit showing the distribution system, but if there were, it would look something like a network of "spaghetti" indicating that distribution lines are constructed on virtually every street and location where customers are located.

"**Substation**" – HECO has numerous transmission substations and distribution substations throughout the island. Transmission substations are utilized to "step down", or transform the 138 kV voltage to either sub-transmission level (46 kV) or distribution level (25 kV, 13.8 kV, 11 kV, 4 kV). Certain substations (i.e. Kewalo and Kamoku) transform transmission voltage directly to a distribution voltage of 25 kV. Substations consist of power transformers, circuit breakers (used to protect equipment and human life), switches and other apparatus for distribution of electricity from the substation. Square symbols on CA-101 and CA-102 indicate the locations of HECO's transmission and distribution substations. CA-103 shows a very basic depiction of a power system with the demarcation of generation, transmission and distribution systems.

"**Load Center**" – A grouping of electrical load located in a geographical area, usually located in the surrounding vicinity of a substation or group of substations. CA-102 shows the network of 46 kV lines in the vicinity of the Pukele Substation (a.k.a. Pukele Load Center).

"**Line Overload**" – This term can apply to transmission, sub-transmission or distribution lines or circuits. The current carrying component of circuits is typically aluminum wire, stranded together in various configurations. These current carrying conductors (wires) all have a physical limit as to how much power can be transmitted through the conductor. They are typically rated in amperes, which translates to a MVA rating. In addition, most lines have a normal and an emergency rating. Exceeding the ampacity or MVA rating of a line is known as "line overload." Overloading a line can lead to loss of life of the conductor, conductor damage and subsequent failure. Lines are usually taken out of service before this happens by circuit breakers that have sensing devices known as relays. This same concept applies to power transformers and other components that carry electricity. CA-104 demonstrates the concept of line overload. Figure 1 shows a simple electric system delivering power to a single customer. As the customer's load increases, the line overloads as shown in Figure 2. If load continues to increase or remains above the conductor's rating, the line will trip out of service and loss of load will occur.

"**Reliability**" – This term as applied to an electric system can be applied system wide, to substations, lines, or other system elements. The reliability of electric systems are measured in terms of frequency of outages, number of affected customers, duration of outage, number of customers interrupted, etc. HECO documents this data into a uniform report format called the Annual Service Reliability Report. The report contains various indices to quantify system reliability.

"**Contingency**" – In electric system analysis, planners often review the system with various elements out of service (a contingency). Contingency, or contingency analysis, relates to system reliability. Systems are reviewed under these stressed or contingency scenarios to determine the perceived performance of the system during foreseeable outages. Outage of a single element is referred to as an "n-1" contingency; outage of two components is "n-2" and so on. Contingency analysis is a major component of system planning and usually a key element of planning standards and criteria, as is the case with HECO. CA-105 shows two electric systems. Figure 1 is a system with one line feeding a customer. Outage of this line leads to loss of load. Figure 2 is a system with two lines feeding a customer. Loss of one line (n-1 contingency) does not affect the customer, whereas loss of two lines (n-2 contingency) leads to loss of load. A basic concept is that a system that can tolerate n-2 contingencies versus n-1 contingencies is more reliable. As systems are designed for a greater number of contingencies, costs typically follow an upward trend.

"**Planning Criteria**" – This term refers to a minimum set of standards to which electric systems are planned. Usually, as is in the case of HECO, there are generation, transmission, and distribution planning criteria. While these are separate criteria, making improvements or retirements of new equipment in one of these areas impacts the others.

"**Load Flow Analysis**" – Load flows are mathematical models of an electric system. Load flow models contain data for generation, transmission, sub-transmission and distribution elements. The load flows models are utilized to review a system under normal operating conditions, under contingency (stressed) conditions and to test planning criteria for violations of such criteria. CA-104 and CA-105 are very simple load flow models of a hypothetical system. Load flows can be utilized to review component and line loading, reliability of the system (contingency analysis), load distribution and system utilization. As a result, I utilized more complex load flow models to independently assess the need for the EOTP as proposed by HECO.

"**System Utilization**" – This is a term I utilize to quantify the extent to which the existing infrastructure is being utilized. In such a review, the percentage of equipment loading, usually lines and transformers is compared to ratings of the equipment. This review gives an indication to important factors such as load distribution amongst substations, and available capacity for load growth and backup to other equipment during emergencies. CA-106 gives an example of system utilization. The simple system shows two substations each with one transformer. In Figure 1, the system shows a load distribution problem because one transformer is 80% loaded, while the other transformer is only 20% loaded. In this scenario, the transformer with 20% loading is being underutilized. The line feeding transformer A is also overloaded. Figure 2 shows that if a portion of transformer A's load is shifted to transformer B by closing a "tie switch or tie line" both transformers are now better utilized and there is no line overloading. Such an example is simplistic in nature, but is very representative of one of the issues identified in this docket, namely the Koolau/Pukele Overload Situation.

"**Tie Line or Tie Switch**" – This term refers to portions of overhead circuits and/or switches, which can be utilized to shift load from one substation to another, or one circuit to another. In this proceeding the tie lines of relevance are on the 46 kV circuits from Pukele Substation, which have tie points to circuits from Archer Substation. In addition, this docket proposes in essence several new 46 kV tie lines between the Pukele Substation and the Archer Substation, and between the Pukele Substation and the Kamoku Substation.

CERTIFICATE OF SERVICE

I hereby certify that a copy of the foregoing **DIVISION OF CONSUMER ADVOCACY'S DIRECT TESTIMONY AND EXHIBITS** was duly served upon the following parties, by personal service, hand delivery, and/or U.S. mail, postage prepaid, and properly addressed pursuant to HAR § 6-61-21(d).

WILLIAM A. BONNET VICE PRESIDENT–GOVERNMENT AND COMMUNITY AFFAIRS HAWAIIAN ELECTRIC COMPANY, INC. P. O. Box 2750 Honolulu, HI 96840-0001	1 copy
PATSY H. NANBU DIRECTOR – REGULATORY AFFAIRS HAWAIIAN ELECTRIC COMPANY, INC. P. O. Box 2750 Honolulu, HI 96840-0001	1 copy
THOMAS W. WILLIAMS, JR., ESQ. PETER Y. KIKUTA, ESQ. GOODSILL ANDERSON QUINN & STIFEL Alii Place, Suite 1800 1099 Alakea Street Honolulu, HI 96813	1 copy
HENRY Q. CURTIS VICE PRESIDENT FOR CONSUMER ISSUES LIFE OF THE LAND 76 North King Street, Suite 203 Honolulu, HI 96817	3 copies
SCOTT K. SAIKI c/o State Capitol, Room 438 Honolulu, HI 96813	3 copies

KAREN H. IWAMOTO, PRESIDENT PALOLO COMMUNITY COUNCIL 3443 Hardesty Street Honolulu, HI 96816	1 copy
DARLENE NAKAYAMA, PRESIDENT HOOLAULIMA O PALOLO 2525 Makaulii Place Honolulu, HI 96816	1 copy
COREY Y.S. PARK, ESQ. PAMELA W. BUNN, ESQ. PAUL JOHNSON PARK & NILES 1001 Bishop Street Suite 1300, ASB Tower Honolulu, HI 96813	1 copy
DR. JEREMY LAM, PRESIDENT MALAMA O MANOA 2230 Kamehameha Avenue Honolulu, HI 96822	1 copy
DAISY M. MURAI, SECRETARY KAPAHULU NEIGHBORS c/o 3039 Kaunaoa Street Honolulu, HI 96813	1 copy

DATED: Honolulu, Hawaii, June 21, 2005.

Ann Sonokawa
____